IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

POLAROID CORPORATION, Plaintiff and Counterclaim Defendant, v. HEWLETT-PACKARD COMPANY, Defendant and Counterclaim Plaintiff.	C.A. No. 06-738-SLR **REDACTED**

**DECLARATION OF RAYMOND N. SCOTT, JR.
IN SUPPORT OF DEFENDANT HEWLETT-PACKARD'S MEMORANDUM
IN OPPOSITION TO PLAINTIFF POLAROID CORPORATION'S MOTION TO
EXCLUDE DR. RANGARAJ RANGAYYAN'S OPINIONS CONCERNING
OBVIOUSNESS**

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Attorneys for Defendant and Counterclaim-Plaintiff Hewlett-Packard Company

Dated: June 12, 2008

I, Raymond N. Scott, Jr., declare as follows:

1. I am an attorney with Fish & Richardson P.C., counsel for Hewlett-Packard Company. I am a member of the Bar of the State of Delaware and of this Court. I have personal knowledge of the matters stated in this declaration and would testify truthfully to them if called upon to do so.

2. Attached hereto as Exhibit A is a true and correct copy of U.S. Patent No. 4,489,349 issued to inventor Takashi Okada.

3. Attached hereto as Exhibit B is a true and correct copy of U.S. Patent No. 4,829,381 assigned to Polaroid Corporation.

4. Attached hereto as Exhibit C is a true and accurate copy of excerpts from the Deposition of Dr. Rangaraj Rangayyan, dated May 9, 2008.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

Executed this 12th of June, 2008, at Wilmington, Delaware.

/s/ Raymond N. Scott, Jr.
Raymond N. Scott, Jr.

CERTIFICATE OF SERVICE

I hereby certify that on June 12, 2008, I electronically filed with the Clerk of Court the foregoing document using CM/ECF which will send electronic notification of such filing(s) to the following counsel:

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Raymond N. Scott, Jr.

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EXHIBIT A

United States Patent [19] [11] Patent Number: 4,489,349

Okada [45] Date of Patent: Dec. 18, 1984

[54] VIDEO BRIGHTNESS CONTROL CIRCUIT

[75] Inventor: Takashi Okada, Yokohama, Japan

[73] Assignee: Sony Corporation, Tokyo, Japan

[21] Appl. No.: 230,394

[22] Filed: Feb. 2, 1981

[30] Foreign Application Priority Data

Jan. 31, 1980 [JP] Japan 55-10667

[51] Int. Cl.[3] H04N 5/68

[52] U.S. Cl. 358/168; 358/32; 358/164

[58] Field of Search 358/168, 39, 74, 243, 358/32, 164

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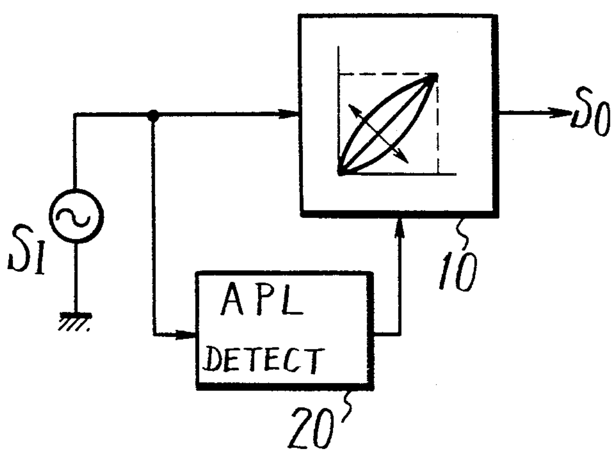
Primary Examiner—Tommy P. Chin
Attorney, Agent, or Firm—Lewis H. Eslinger; Alvin Sinderbrand

[57] ABSTRACT

A control circuit for controlling the relative brightness of a video signal includes an average picture level (APL) detector to measure the average brightness of the video signal and a brightness control circuit responsive to the detected average brightness to provide an output video signal wherein the picture areas containing most of the picture information are corrected to give greater contrast. In the output signal, portions corresponding to the black and peak white levels of the incoming video signals are provided substantially at the black and peak white levels, respectively, while the average brightness level of the output video signal is provided at an optimum level, such as 50%. The brightness control circuit can include a variable gamma correction circuit in which the value of gamma is automatically determined by a control signal provided from the APL detector.

21 Claims, 13 Drawing Figures



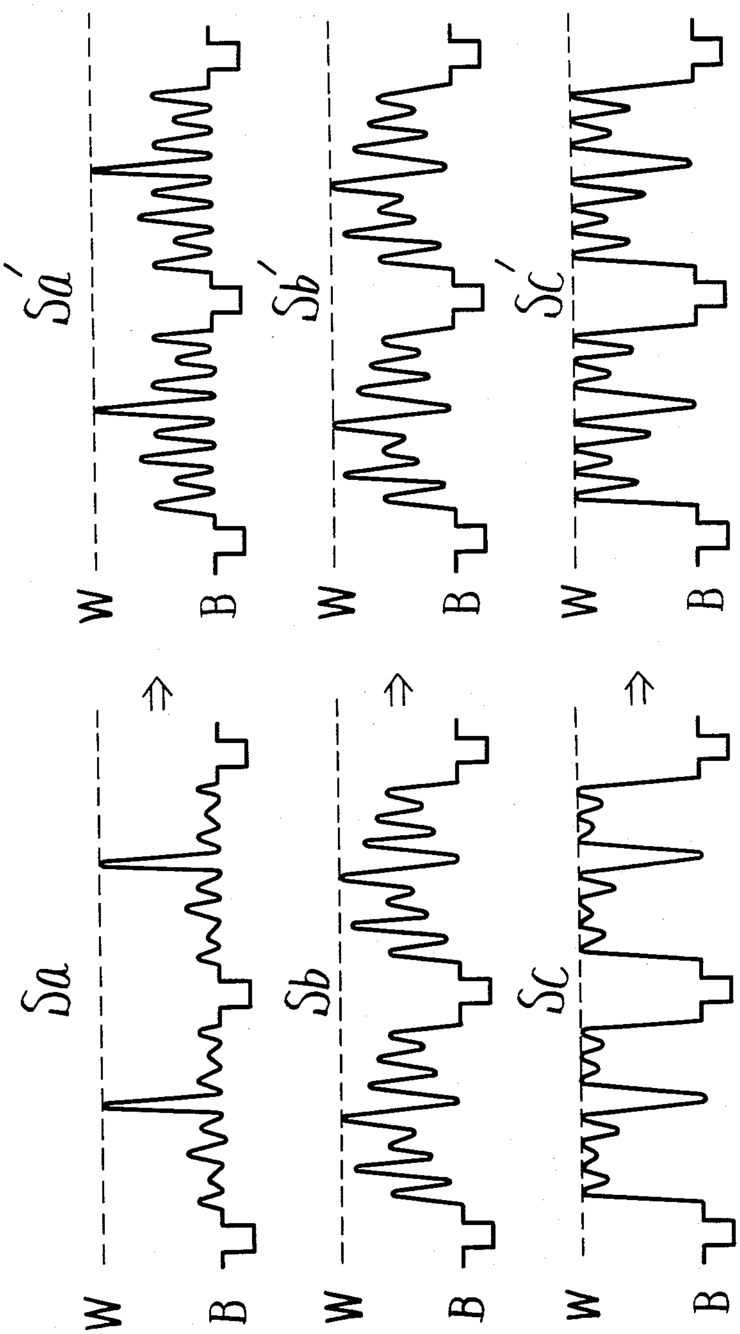


FIG. 1

FIG. 2

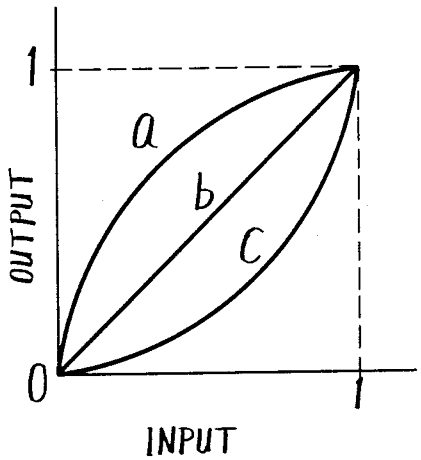


FIG. 3

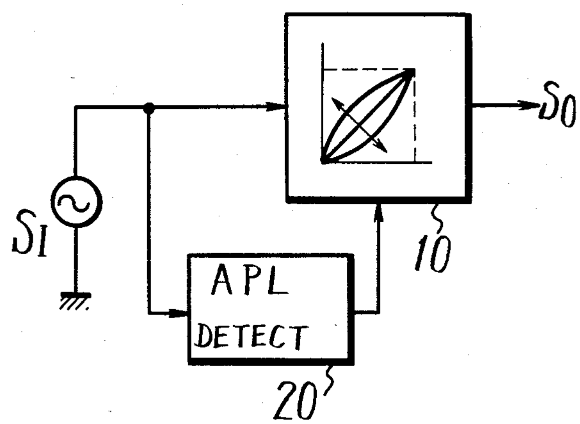


FIG. 4

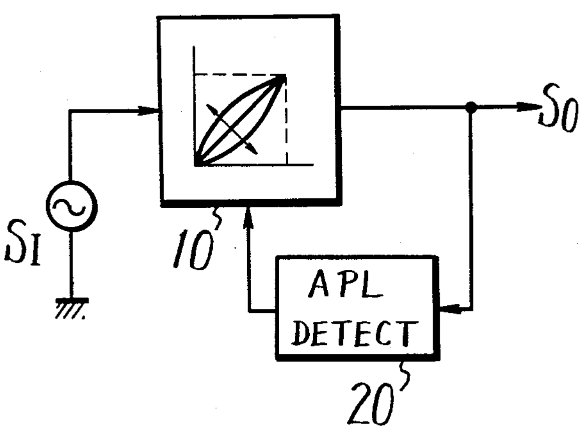


FIG. 5

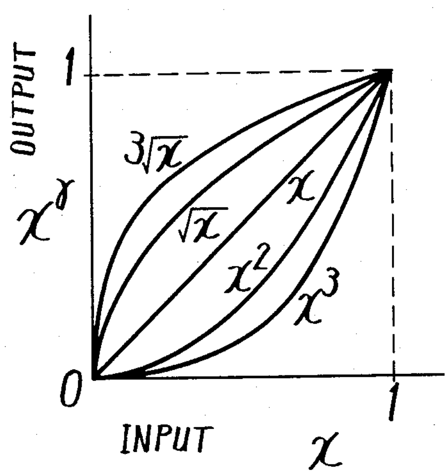


FIG. 6

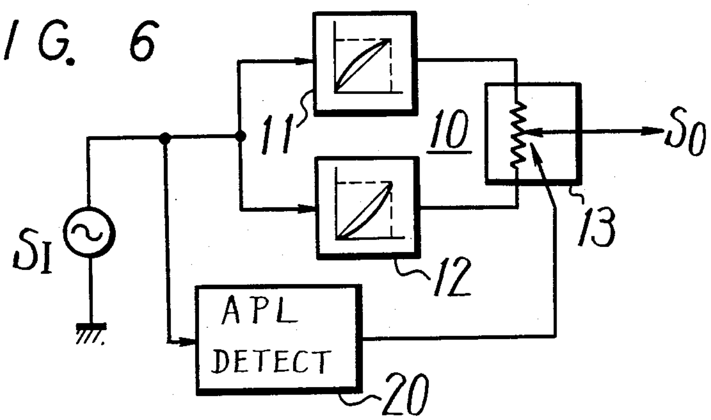
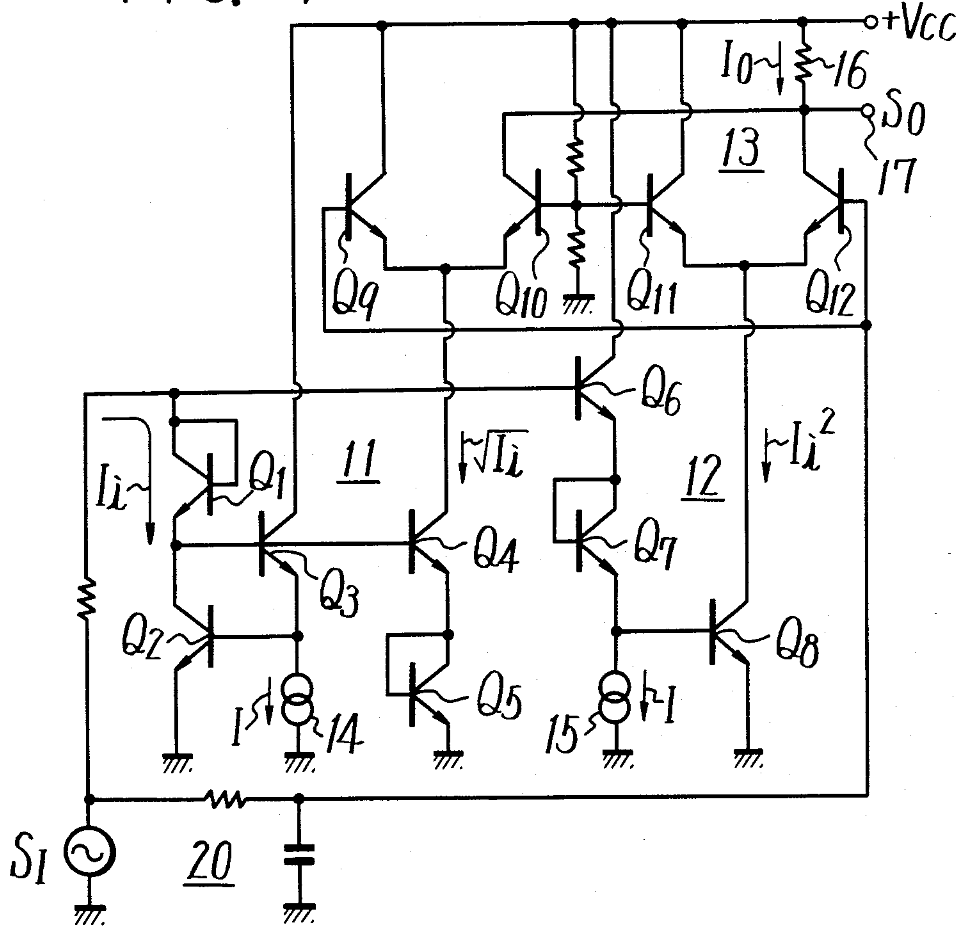

11
10
S0
13
SI
12
APL DETECT
20

FIG. 7


+Vcc
I0
16
S0
13
17
Q9
Q10
Q11
Q12
Q6
Ii
Q1
11
√Ii
12
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Q4
Q7
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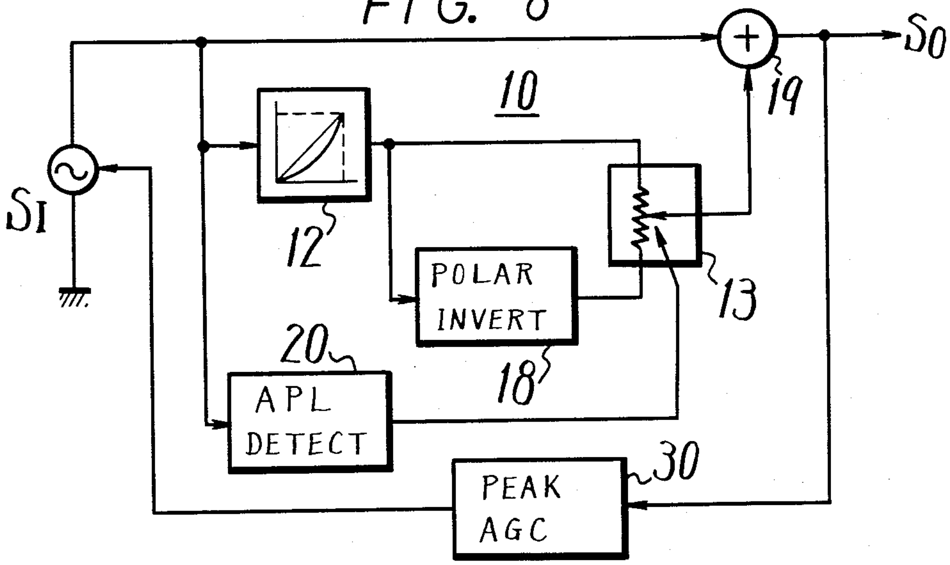
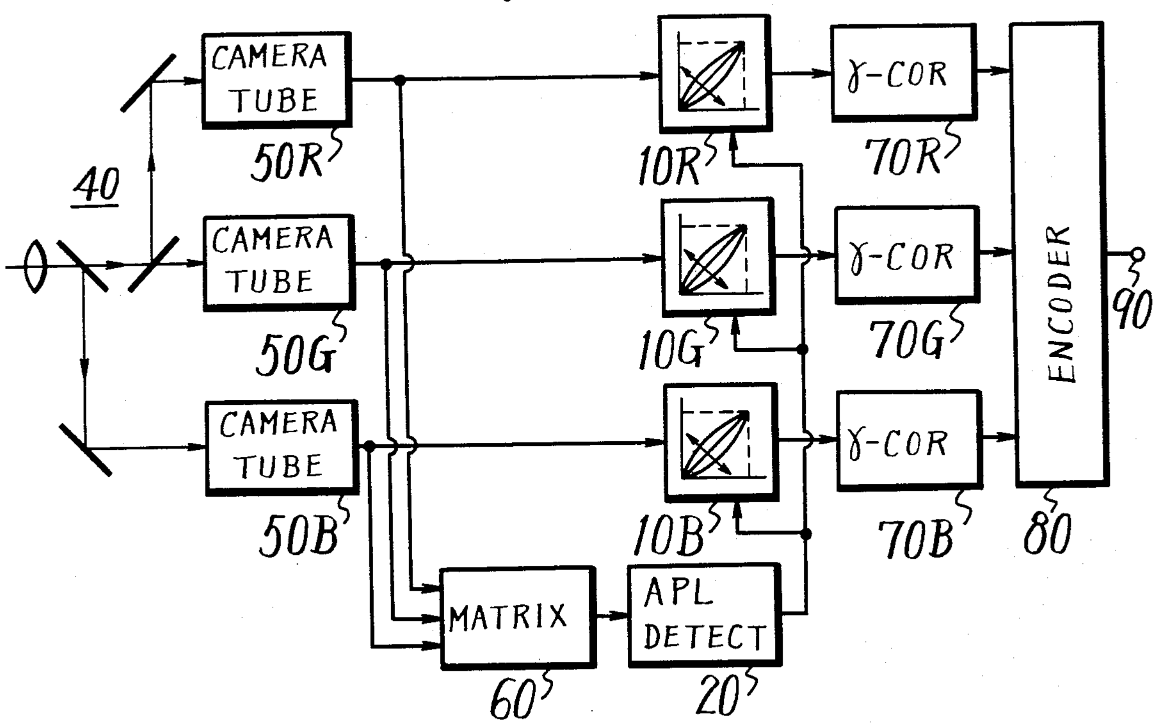
Q8
Q5
I
14
15
I
SI
20

FIG. 8



So
19
10
SI
12
13
POLAR INVERT
20
APL DETECT
18
30
PEAK AGC

FIG. 9



CAMERA TUBE
50R
10R
γ-COR
70R
40
CAMERA TUBE
50G
10G
γ-COR
70G
ENCODER
90
CAMERA TUBE
50B
10B
γ-COR
70B
80
MATRIX
60
APL DETECT
20

FIG. 10

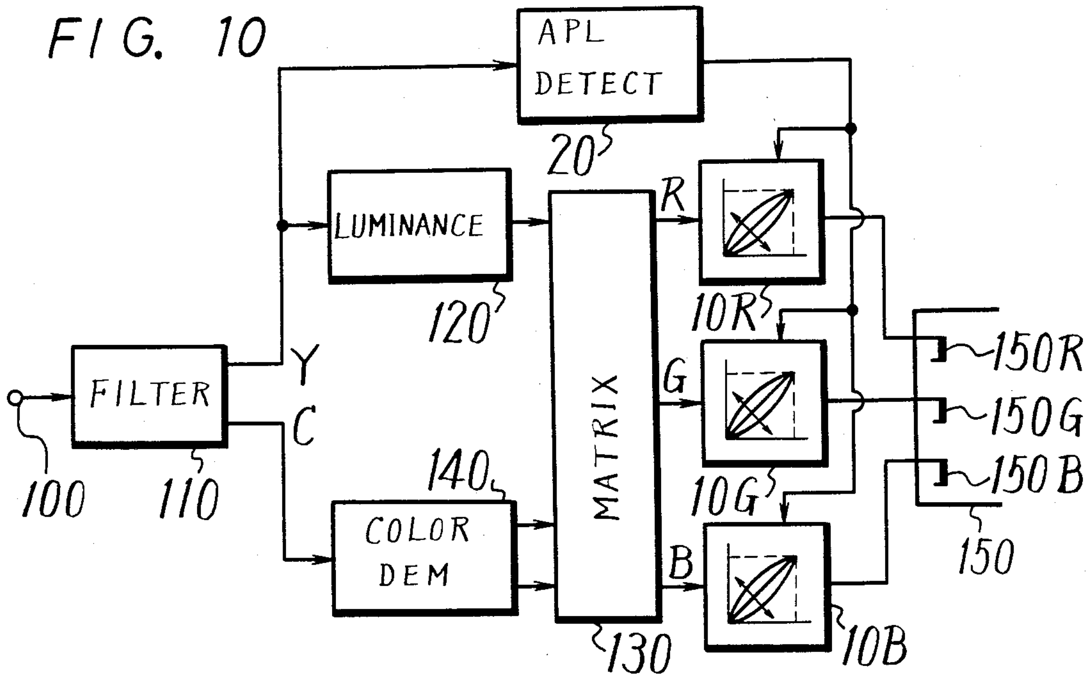


FIG. 11

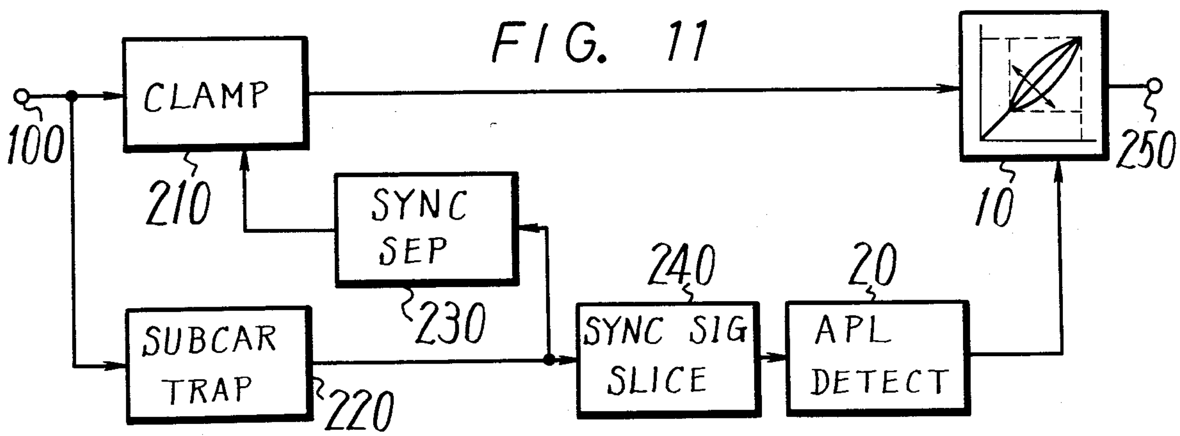
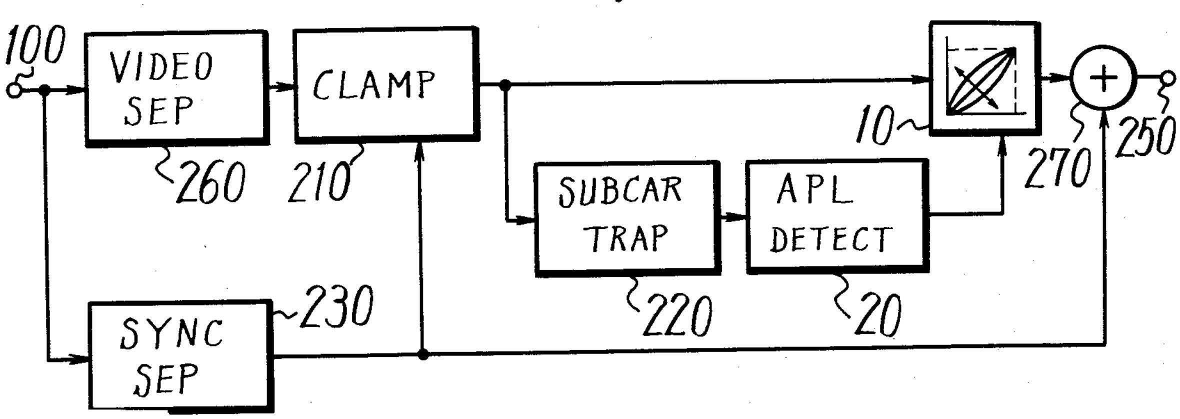
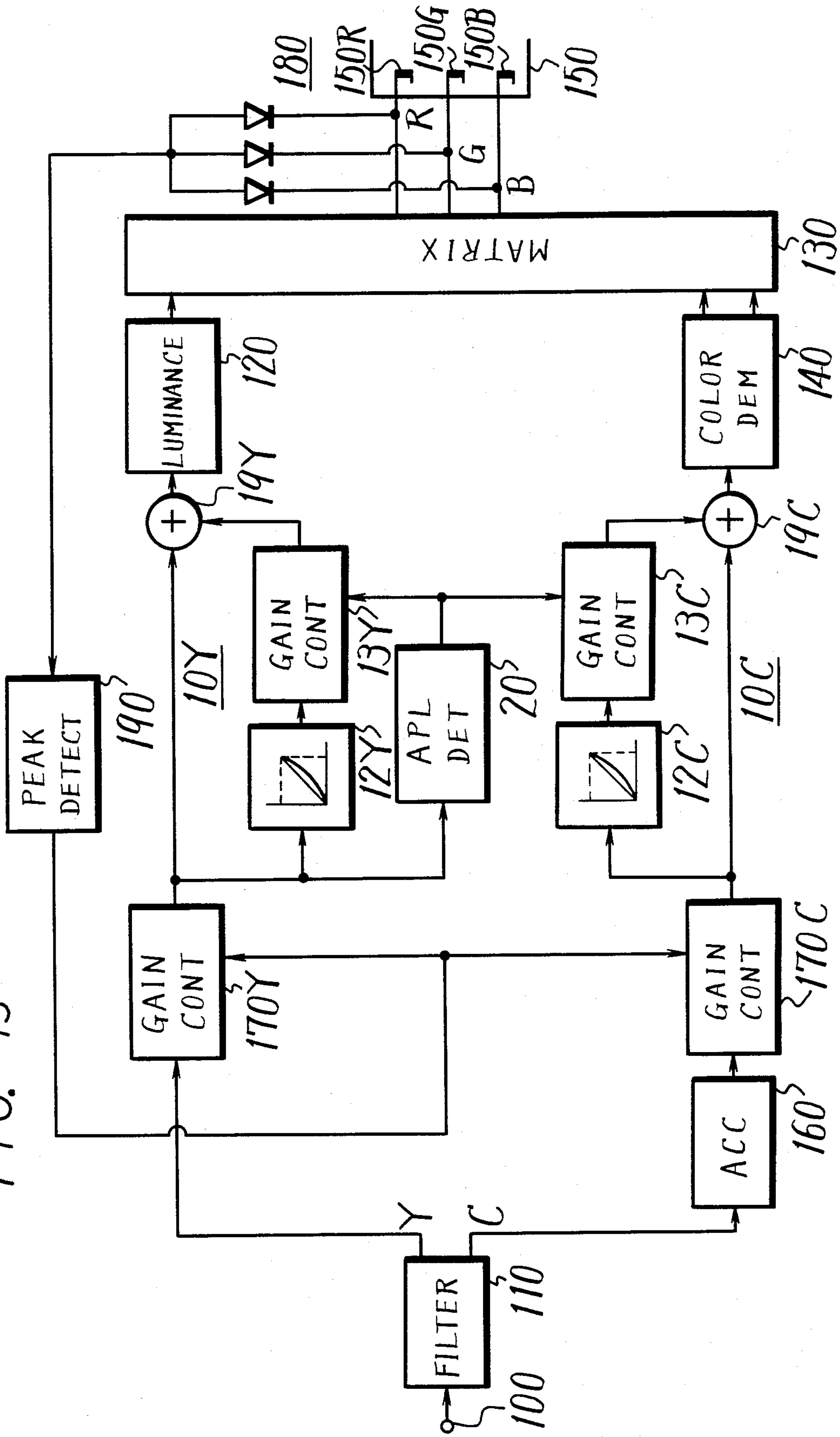


FIG. 12

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150B
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APL DET
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GAIN CONT
13C
10Y
10C
12Y
12C
PEAK DETECT
190
GAIN CONT
170Y
GAIN CONT
170C
ACC
160
Y
C
FILTER
110
100

FIG. 13

VIDEO BRIGHTNESS CONTROL CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to video signal processing circuitry and particularly relates to circuitry for controlling the brightness of a video signal so that detail of interest in a video picture will appear natural and have good contrast.

2. Brief Description of the Prior Art:

Natural illumination can have an extremely wide brightness range, and will necessarily have a vast range of contrast scales. The human eye adapts itself remarkably well for viewing naturally-lit objects and can with ease perceive detail in shadows and in brightly lit areas as well. Nevertheless, color video cameras and color video display apparatus are not easily adaptable to conditions of natural illumination, and current videocasting practices require special techniques, such as supplemental fill-in lighting, to provide a pleasing yet natural picture.

However, when such special techniques are unavailable, such as during on-scene news reporting, the picture presented on a display apparatus can be harsh and unpleasant. For example, if an on-the-spot newscast takes place at night with a newscaster at the news scene standing in front of a bright source, such as a flashing neon sign, the picture is likely to be harsh and without good detail. In such a scene, the presentation of the neon light is bright but the other objects in the picture are dark, and the contrast range among such objects is extremely narrow. Thus, except for the neon sign, the picture appears objectionably dim and observation of detail in the picture is difficult.

This problem can be understood by considering that while a color camera can be responsive to input light having an illumination range of from several hundred to several hundred thousand lux, the electrical output of the camera is limited to a range of, for example, 1 volt peak-to-peak. The input light must have a limited illumination range, e.g. 100 to 200 lux or several thousand to several tens of thousands of lux, in order that all of the video output signal remain within the range of 1 volt peak-to-peak. If these illumination limits are not observed, a conventional color television camera and display apparatus will not provide a good, pleasing picture.

Brightness adjustment in the video transmission is now carried out to a limited extent by use of so-called gamma (γ) correction. This process compensates for the differences in gamma values between the image pickup tube of a television camera and the cathode ray tube (CRT) of a television receiver.

Normally, the picked-up image is gamma-corrected before transmission so that the net gamma value of the image pickup and image display will be unity.

Conventionally, gamma correction is carried out on the image pickup side so that the output signal is skewed logarithmically at the saturated (white) side of the brightness range. Then, the skewed curve is expanded somewhat at the CRT, due to its inherent gamma characteristic, so that the picture brightness is correct.

Generally, if the overall gamma characteristic is logarithmic, the dark picture portions will have expanded contrast, and fine dark or shadow detail is reproduced. Conversely, if the gamma characteristic is exponential,

the bright portions will have expanded contrast, and detail in brightly lit areas will be clear.

Further, the lower illumination intensity portions of the video signal are affected by noise in the video apparatus. Consequently, a good video picture cannot be obtained for any scene unless the picture brightness is properly adjusted to span the entire dynamic range of the video apparatus. Accordingly, the actual brightness of an object in the scene does not convert exactly to a particular level of the video output signal, especially if the object is not evenly illuminated. The image of such an object in an unevenly-lit scene is not easily visible when reproduced on a video screen, and hence fatigues the eyes, making viewing somewhat tiring and unpleasant.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a technique wherein an image on a video screen is provided with the portion of the picture of most interest having relatively high contrast.

It is a further object of this invention to provide a correction circuit for use, for example, in a color television receiver, which will automatically adjust the brightness of the television signal so that a pleasing picture is presented on the display screen of the receiver, even when the scene is unevenly illuminated.

According to an aspect of this invention, a control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level, such as the black level, and a peak bright level, such as the peak white level, about an average brightness level comprises an average picture level (APL) detector for detecting the average brightness level and, in response, providing a corresponding control signal, and a brightness adjusting circuit for optimizing the brightness of the video signal in response to the control signal, and providing a video output signal in which respective portions of the video output signal corresponding to portions of the incoming video signal at the peak dark level and the peak bright level are provided at the peak dark level and the peak bright level, but in which the average picture level is provided at an optimum level, such as the 50% brightness level.

The brightness adjusting circuit can favorably be formed as an adjustable gamma circuit, in which the value of gamma is determined in accordance with the control signal from the APL detector. In other words, the brightness adjusting circuit has an input-output characteristic such that for a video input signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, the video output signal is provided at a level proportional to a value X^{γ}, and the value γ is automatically determined in response to the control signal so that the video output signal has an APL at the optimum level.

A correction circuit according to this invention can be incorporated into a color television camera, in which case three brightness adjusting circuits can be included to be operative on respective primary color signals. The circuit of this invention can also be incorporated in a color television receiver. In such case, three brightness adjusting circuits can be provided, each operative upon a separate primary color signal, a single brightness adjusting circuit, operative upon both the chrominance and luminance components of a composite color video signal can be provided, or, alternatively, two brightness

adjusting circuits can be provided, one operative upon the luminance component, the other operative upon the chrominance component of a composite color video signal.

Various other features and advantages of the present invention will be apparent from the following description of several preferred embodiments, when considered with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a set of charts showing video waveforms before and after treatment in the correction circuit of this invention.

FIG. **2** is an input-output graph for explaining the operation of a portion of the correction circuit of this invention.

FIGS. **3** and **4** are diagrammatic views showing the basic construction of the circuit of this invention.

FIG. **5** is an input-output graph for explaining the present invention.

FIG. **6** is a systematic block diagram showing one embodiment of the correction circuit of this invention.

FIG. **7** is a detailed circuit diagram showing a practical example of the embodiment of FIG. **6**.

FIG. **8** is a systematic block diagram showing another embodiment of the circuit of this invention.

FIG. **9** is a systematic block diagram of a three-tube color television camera incorporating the present invention therein.

FIG. **10** is a systematic block diagram of a portion of a video display apparatus incorporating the present invention.

FIGS. **11** and **12** are systematic block diagrams of video signal processing circuits for use in video receivers and incorporating the present invention.

FIG. **13** is a systematic block diagram of a portion of a video receiver incorporating the present invention.

DETAILED DESCRIPTIONN OF SEVERAL PREFERRED EMBODIMENTS

With reference to the drawings, and initially to FIG. **1**, typical video signals Sa, Sb, Sc will be considered. In the charts of FIG. **1**, the video signals have an amplitude ranging between a black level B and a peak white level W. Each of the video signals Sa, Sb, Sc, has a broad brightness amplitude range extending from black to white.

The signal Sa represents a dimly-lit scene having a single bright portion. In this case, most of the picture detail is in dark tones in the dimly lit portion, and only a small portion of the picture is bright. As a result, the signal-to-noise ratio of the picture is quite low and the signal Sa produces a dirty or hazy picture.

In the signal Sb, bright and dark tones are substantially uniformly distributed, indicating that the televised scene is ideally illuminated. The entire dynamic range of the signal Sb is used effectively so that the signal Sb has a high signal-to-noise ratio, and will produce a fine quality picture.

The signal Sc represents a scene which is brightly lit, but which includes a dark object. Here most of the detail is in bright tones, and the brightness of the picture will cause such detail to become very faint. Signals such as the signal Sc occur rather often when televising scenes out of doors, especially scenes including snow or scenes at a beach.

As aforesaid, the video signals Sa and Sc, although faithfully corresponding to the objects in the respective televised scenes, include detail in the dimly and brightly lit portions, respectively, which will not be easy to see, due to the limited signal-to-noise ratio of the video display apparatus. According to this invention, the video signals Sa and Sc have their brightness levels optimized so that important detail in the picture portions having the largest amount of picture information can be observed with good contrast. Consequently, the image displayed on the video screen will be pleasing and easy to view.

In order to achieve this, the video signal is processed through a circuit having an input-output characteristic as shown in FIG. **2**.

When the signal Sa is supplied an input, the input-output characteristic is caused to follow curve a of FIG. **2** so that the dimly-lit portions are expanded in contrast while the brightly-lit portions are compressed in contrast, with the result that the processed video signal Sa' is provided as an output video signal.

When the signal Sc is applied as an input, the input-output characteristic thereof follows curve c, so that the brightly-lit portions of the video picture are expanded, while the dimly-lit portions are compressed, so that an output signal Sc' is provided as shown in FIG. **1**.

Finally, when the signal Sb is applied as an input, the input-output characteristic becomes a linear function as shown by curve b in FIG. **2**, so that the output signal Sb' is provided, and the latter is identical with the input signal Sb.

In order to optimize the output video signals Sa' Sb', and Sc', the input-output characteristic must be changed continuously and automatically according to the information distribution of the input signals Sa, Sb, and Sc. Because the picture information distribution is akin to the proportional amount of bright and dimly-lit portions of the picture, the information distribution can be easily obtained by detecting the average picture level (APL) of the input signals Sa, Sb, and Sc. In other words, when the amount of informationn near the black level B is great, as in the signal Sa, the APL will be low. By contrast, when the amount of information near the peak white level W is great, as in the signal Sc, the APL will be high. Because the Sb has information distributed uniformly between the back B and peak white level W, the signal Sb will have an APL of about 50%.

Accordingly, the input-output characteristic a of FIG. **2** is selected for low APL values, the characteristic c is selected for high APL values, and the linear characteristic b is selected when the APL is at or near its optimum level of 50%. Further, when the APL is at some intermediate level, the input-output characteristic can be selected intermediate the curves a and b or intermediate the curves b and c.

Throughout the following description of various embodiments of this invention, common elements will be identified with the same reference characters, and a description of such elements will be provided only with respect to the embodiment with which they are first introduced.

One embodiment showing the basic construction of a correction circuit according to this invention is illustrated in FIG. 3. A video input information signal Si is furnished to an input of a variable correction circuit **10** and is also furnished to an APL detecting circuit **20**. The latter detects the APL of the input signal Si and provides a control signal to a control input of the variable correction circuit **10**. The variable correction circuit **10** automatically adjusts its input-output character-

istic in response to the control signal, and thus also, the input-output characteristic varies as a function of the detected APL. Consequently, the variable correction circuit provides an optimized output signal S_O.

Another example of the control circuit of this invention is shown in FIG. **4**, wherein the output signal S_O is fed back to the APL detecting circuit **20**, so that the input-output characteristic of the variable correction circuit **10** is determined in accordance with the average picture level of the output signal S_O.

The open-loop configuration of FIG. **3** has the advantage of fast and reliable response to changes in APL, while the closed-loop configuration of FIG. **4** has the advantage of superior accuracy in correcting the brightness characteristic of the video signal.

Practical input-output characteristics of the variable correction circuit are illustrated in FIG. **5**, in which the absissa represents an input while the ordinate represents an output X^γ. Here, the input and output remain between values of "0" (representing the black level) and "1" (representing the peak white level). The value of γ is changed according to the detected APL value. For example, when the APL is detected to be below 50%, γ is selected as $\delta=\frac{1}{2}$, and the output becomes $\sqrt{X}$; when the detected APL is at 50%, γ is selected as unity, and the output becomes X; and when the detected APL is above 50%, γ is selected as $\gamma=2$, and the outout becomes X^2. For extreme values of the detected APL, γ can be selected as $\gamma\pm\frac{1}{3}$ so that the output becomes $\sqrt[3]{X}$ when the detected APL is extremely low, and $\gamma=3$ so that the output becomes X^3 when the detected APL is extremely high.

A practical embodiment of the correction circuit of this invention is shown in FIG. **6**, and the details thereof are illustrated in FIG. **7**. In this embodiment, the variable correction circuit **10** is composed of a first correction circuit **11** having an input-output characteristic of $\gamma=\frac{1}{2}$ (i.e., a square-root circuit with an output $\sqrt{X}$), and a second correction circuit **12** having an input-output characteristic of $\gamma=2$ (i.e., a squaring circuit with an output X^2). When the input video signal S_I is applied to respective inputs of each of the first and second correction circuits **11** and **12**, the latter in turn provide first and second corrected video signals which are proportional to $\sqrt{X}$ and X^2, respectively. A summing circuit **13** combines the first and second corrected video signals in proportional amounts depending on the value of the control signal from the APL detector **20**. Thus, when the APL is low, only the first corrected video signal $\sqrt{X}$ is provided. When the APL is high, only the second corrected video signal $\sqrt{X}$ is provided. When the APL is determined to be 50%, the first and second corrected video signals are provided in equal amounts so that the output signal S_O has the output characteristic

$$\frac{\sqrt{X}+X^2}{2},$$

that is, the output signal S_O will be approximately the same as the input signal S_I. It should be noted that for $0<X<1$, the value of the expression

$$\frac{\sqrt{X}+X^2}{2}$$

will be very close to the value $X(\gamma=1)$, and the two expressions will have the same value at 0, 1, and approximately 0.38.

In the practical circuit shown in FIG. **7**, the first correction circuit **11** includes a constant current source **14**; a diode-connected transistor Q_1, having its base and collector connected together to receive an input signal current I_i; an auxiliary transistor Q_2 having its collector coupled to the emitter of the transistor Q_1 and its emitter connected to ground; an input transistor Q_3 having its collector connected to a voltage source V_{CC}, its base connected to the emitter of the transistor Q_1, and its emitter coupled to the constant current source **14** and also to the base of the transistor Q_2; and an output transistor Q_4 having its base connected to the base of transistor Q_3 and the emitter of the transistor Q_1, and its collector providing the first output correction signal current $\sqrt{I_i}$. A diode-connected transistor Q_5 is connected between the emitter of the transistor Q_4 and ground.

The second correcting circuit **12** includes a constant current source **15**, and input transistor Q_6 having its base connected to receive the input signal S_I and its collector connected to the voltage source V_{CC}; a diode-connected transistor Q_7 having its base and collector connected to the emitter of the transistor Q_6 and its emitter connected to the constant current source **15**; and an output transistor Q_8 having its base connected to the emitter of the transistor Q_7, its emitter connected to ground, and its collector providing a second output correction signal current I_i^2.

The summing circuit **13** is formed of a load resistor **16** connected to the voltage source V_{CC}; a first transistor Q_9 having its collector connected to the voltage V_{CC} and its base connected to receive the control signal from the APL detecting circuit **20**; a second transistor Q_{10} having its collector connected to the load resistor **16** and its emitter, together with the emitter of the first transistor Q_9 connected to the collector of the output transistor Q_4. The summing circuit **13** also includes a third transistor Q_{11} having its collector connected to the voltage source V_{CC}, and its base together with the base of the transistor Q_{10} biased at a predetermined level. Also included is a fourth transistor Q_{12} having its collector connected to the load resistor **16**, its base connected to receive the control signal from the APL detecting circuit **20**, and its emitter, together with the emitter of the third transistor Q_{11} connected to the collector of the output transistor Q_8. An output terminal **17** is connected to the junction of the load resistor **16** with the collectors of the transistors Q_{10} and Q_{12}.

In this embodiment, the APL detecting circuit **20** is a low-pass filter composed of a resistor and a capacitor.

The specific operation of the embodiment depicted in FIG. **7** is explained as follows:

In this circuit, if equal constant currents I are provided from each of the constant current sources **14** and **15**, the base-emitter forward voltages of the transistors Q_1 to Q_8 are represented as V_{BE1} to V_{BE8}, respectively, and the transistors Q_1 to Q_8 have respective collector currents I_1 to I_8, respectively, the following relationship is obtained:

$$V_{BE2}+V_{BE3}=V_{BE4}+V_{BE5} \tag{1}$$

As is well known, the base-emitter forward voltage V_{BE} of a transistor can be expressed as a function of its collector current I_c and the saturation current I_s thereof according to the following equation:

$$V_{BE}=KT/g \ln Ic/I_s \quad (2)$$

where g is an electric charge constant relating to the number of charge carriers in the base-emitter junction, K is the Boltzmann constant, and T is a constant having units of temperature. Accordingly, the currents of the transistors Q_2 to Q_5 will have the relationship

$$I_2 \cdot I_3 = I_4 \cdot I_5 \quad (3)$$

In this circuit, I_2 is equal to the input current I_i, I_3 is equal to the current I of the constant current source **14**, and I_4 is equal to I_5, so that the latter currents can be expressed as $I_4=I_5=I_m$. Accordingly, the following relationship results:

$$I_i \cdot I = I_m^2 \quad (4)$$

that is,

$$I_m = \sqrt{I} \cdot \sqrt{I_i} \quad (5)$$

If it is assumed that the current I of the constant current source **14** is unity, then I=1, and

$$I_m = \sqrt{I_i} \quad (6)$$

Thus, the first correction circuit **11** has a gamma of ½.

At the same time, in the second correction circuit **13**, the base-emitter voltages of the transistors Q_6, Q_7, and Q_8 can be expressed

$$V_{BE1}+V_{BE3}+V_{BE2}=V_{BE6}+V_{BE7}+V_{BE8} \quad (7)$$

and the respective collector currents can be expressed as

$$I_1 \cdot I_3 \cdot I_2 = I_6 \cdot I_7 \cdot I_8 \quad (8)$$

In addition, because the currents I_1 and I_2 are each equal to the input current I_i, and the currents I_3, I_6, and I_7 are each identical with the current I from the constant current source **15**, if the current I_8 is expressed an I_n, the following relationship results:

$$I_i^2 \cdot I = I^2 \cdot I_n \quad (9)$$

or

$$I_n = (1/I) \cdot I_i^2 \quad (10)$$

thus, if, as aforesaid, the current I is unity, then

$$I_n = I_i^2 \quad (11)$$

Consequently, the second correction circuit **12** has a gamma of 2.

In the summing circuit **13**, a current $k \cdot \sqrt{I_i}$ flows through the collector of the second transistor Q_{10} while a current of $(1-k)I_i^2$ flows through the collector of the fourth transistor Q_{12}, where k is a positive number less than unity which is determined according to the average picture level voltage from the APL circuit **20**. As a result, an output current I_O flows through the load resistor **16**, and can be expressed as follows:

$$I_0 = k\sqrt{I_i} + (1-k)I_i^2 \quad (12)$$

In other words, when the APL is detected to be extremely low, the transistors Q_9 and Q_{12} are rendered nonconductive so that the constant k is unity, and the output current I_O equals the current $\sqrt{I_i}$ from transistor Q_4. When the APL is approximately 50%, k=½, and the output current I_O can be expressed.

$$I_0 = \frac{\sqrt{I_i} + I_1^2}{2}.$$

When the APL is determined to be high, the second and third transistors Q_{10} and Q_{11} are rendered nonconductive so that the constant k=0 and I_O can be expressed

$$I_0 = \sqrt{I_i}.$$

Of course, for intermediate values of the detected APL, the constant k will take on intermediate values of gamma so that the output signal S_O will provide a video picture of optimum contrast.

Another embodiment of the correction circuit according to this invention is illustrated in FIG. **8**. In this embodiment, the variable correction circuit **10** is formed of the squaring circuit **12** having its input coupled to receive the input signal S_i, a polarity inverter **18** coupled to the output of the squaring circuit **12**, and the summing circuit **13** connected to combine the output of the squaring circuit **12** with an inverted replica thereof provided from the polarity inverter **18**. Also in this embodiment, an adder **19** is included to combine the input video signal with the resultant video signal provided from the summing circuit **13**.

The summing ratio of the corrected signal from the squaring circuit **12** and the inverted replica thereof is changed according to the control signal furnished from the APL detector **20**. Since the output of the polarity inverter **18** is expressed as $-X^2$, the output of the summing circuit **13** can be expressed as

$$mX^2-(1-m)X^2=(2m-1)X^2$$

so that the output signal from the adder **19** can be expressed as

$$X+(2m-1)X^2.$$

Hence, the input-output characteristic of the variable correction circuit **10** is changed according to the value of m in accordance with the detected average picture level. However, in order to maintain the brightness range of the output video signal S_O as a constant, a peak automatic gain control circuit **30** is coupled from the output of the adder **19** back to a point in advance of the variable correcting circuit **10**.

It should be noted that in this embodiment if the value of m is selected as ¼, the variable correction circuit **10** will have a gamma approximately ½, if the value of m is selected as ½, the gamma will be unity, and if the value of m is selected as 1, the gamma will be 2.

FIG. **9** illustrates a three-tube type color television camera incorporating a correction circuit according to the present invention. In this camera, an optical system

40 separates the image into red, green, and blue images which are incident on respective red, green, and blue image pickup tubes **50R**, **50G**, and **50B**. As a result, the latter provide respective red, green, and blue color signals. These color signals are provided to a matrix circuit **60** which then derives from them a luminance signal and supplies the same to the APL detector **20**. In this embodiment, respective variable correction circuits **10R**, **10G**, and **10B** are provided to control the brightness of the corresponding red, green, and blue color signals. The control signal from the APL detector **20** is provided to each of the vertical correction circuits **10R**, **10G**, and **10B** to control their respective input-output characteristics. Then, the corrected red, green, and blue color signals from the circuits **10R**, **10G**, and **10B** are supplied through respective γ-correction circuits **70R**, **70G**, and **70B** to an NTSC encoder **80**, and the latter provides an encoded composite color video signal at an output terminal **90** thereof.

If instead of a plural-tube camera, a single-tube type color camera is employed, in which the luminance signal is separated, the average picture level of the luminance signal can be detected without the necessity of employing the matrix circuit **60**.

A television receiver incorporating a correction circuit according to this invention is illustrated in FIG. **10**. In this receiver, a composite color video signal applied to an input terminal **100** thereof is separated in a filter circuit **110** into a luminance component Y and a chrominance component C. The luminance component Y is furnished through a luminance signal processing circuit **120** to a matrix circuit **130**, and is also furnished to the APL detector **20**. The chrominance component C is furnished to color demodulator **140** which then supplies a pair of color difference signals to the matrix circuit **130**. The latter then provides primary color signals R, G, and B to a color cathode ray tube **150**. In this receiver, respective variable correction circuits **10R**, **10G**, and **10B** are provided between the matrix circuit **130** and respective cathodes **150R**, **150G**, and **150B** of the color cathode ray tube **150**. Here, the separated red, green, and blue color signals are adjusted in brightness according to the average luminance level detected by the APL detector **20**.

Another embodiment of this invention is illustrated in FIG. **11**, in which the luminance component and the chrominance component are not separated, as they are in the embodiment of FIG. **10**. In this embodiment, the composite color video signal is applied from the input terminal **100** to a clamp circuit **210** and thence to the variable correction circuit **10**. The composite color video signal is also supplied to a subcarrier trap circuit **220**, which blocks the chrominance component modulated on the subcarrier, so that only the luminance signal and the synchronizing pulse are passed. The synchronizing pulse is separated out therefrom in a synch separator **230** and is furnished to the clamp circuit **210** so that the latter can clamp the video signal to the pedestal level of the synchronizing pulse. The luminance component is furnished from the subcarrier trap **220** through a synch signal slice circuit **240** to the APL detector **20**. A corrected composite color video signal is then applied from the variable correction circuit **10** to an output terminal **250**. In this embodiment, the variable correction circuit **10** has an input-output characteristic that varies as a function of the control signal from the APL detector **20** during the line scanning portion of the video signal, but has a linear input-output characteristic ($\gamma=1$) during the occurrence of the synchronizing pulse.

Another embodiment of the correction circuit of this invention is illustrated in FIG. **12**. It should be appreciated that the embodiment of FIG. **12** is a variation of the embodiment of FIG. **11**. In this embodiment, the luminance and chrominance components are not separated from one another, but the synchronizing pulse is separated out and is treated separately. Here, a video separator **260** is coupled to the input terminal **100** so that only the luminance and chrominance components are furnished to the clamp circuit **210**. The synch separator **230** is coupled in advance of the video separator **260**, and the separated synchronizing pulse is furnished therefrom to the clamp circuit **210** and also to an adder circuit **270** disposed after the variable correction circuit **10**. The composite color video signal, without the synchronizing pulse, is applied to the clamp circuit **210** where it is clamped to the pedestal level of the synchronizing pulse from the synch separator **230**, and the thus-clamped color video signal is supplied to the variable correction circuit **10**. The clamped color video signal is also supplied through the subcarrier trap circuit **220** to the APL detector **20** which detects the average picture level of the luminance component. The APL detector **20** then furnishes a control signal to the variable correction circuit **10** to control its input-output characteristic. Then, the corrected color video signal from the variable correcting circuit **10** is combined in the adder circuit **270** with the separated synchronizing pulse, so that a finally corrected composite color video signal is provided at the output terminal **250**.

Yet another video receiver incorporating the correction circuit according to this invention is illustrated in FIG. **13**. This video receiver combines the features of this invention with a circuit for dynamically controlling the amplitude of the video signal according to the picture contents, i.e., a so-called dynamic picture control circuit. Examples of such a dynamic picture control circuit are disclosed in U.S. Pat. No. 4,403,254, issued Sept. 6, 1983, and U.S. Pat. No. 4,298,885, issued Nov. 3, 1981, both of which have a common assignee herewith.

As illustrated in FIG. **13**, the separated luminance signal is furnished from the filter **110** to a luminance gain control circuit **170Y** and is then furnished to a luminance correction circuit **10Y**. The latter is formed in general like the embodiment of FIG. **8**, and includes a squaring circuit **12Y**, a gain control circuit **13Y**, and an adder circuit **19Y**. A corrected luminance signal is furnished from the adder circuit **19Y** through a luminance processing circuit **120** to the matrix circuit **130**. The luminance component Y is also furnished from the gain control circuit **170Y** to the APL detector **20** which then detects the average luminance component. The chrominance component C is furnished through an automatic chroma control (ACC) circuit **160** to a chrominance gain control circuit **170C**, and thence to a chrominance correcting circuit **10C**. This circuit **10C** is basically similar to circuit **10Y** and to the embodiment of FIG. **8**, and includes a squaring circuit **12C**, a gain control circuit **13C**, and an adder circuit **19C**. The corrected chrominance signal is then furnished from the adder circuit **19C** to the color demodulator **140** which provides demodulated color difference signals to the matrix circuit **130**.

The matrix circuit **130** provides decoded primary color signals R, G, and B to the cathodes **150R**, **150G**,

and **150B** and also to a minimum value detecting circuit **180**, which here includes diodes having their cathodes connected to the cathodes **150R**, **150G**, and **150B** of the cathode ray tube **150** and having their anodes connected to a peak detecting circuit **190**. The output of the peak detecting circuit **190** then controls the gain of the gain control circuits **170Y** and **170C**.

In this embodiment, the control signal from the APL detector **20** is furnished to both the gain control circuit **13Y** and the gain control circuit **13C** of the respective luminance and chrominance variable correcting circuits **10Y** and **10C**.

In each of the above embodiments of this invention, the brightness of a video signal is automatically controlled according to the information carried within the video signal, thereby providing an optimum contrast ratio to that portion of the video picture having the greatest amount of information. As a result, according to this invention, it is possible to provide a reproduced picture which is natural and pleasing to the eye, and which has sufficient contrast so that the picture is neither harsh nor washed out.

Although certain preferred embodiments of this invention have been described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by persons skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims.

What is claimed is:

1. A control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level and a peak bright level about an average brightness level comprising:

brightness controlling means having a signal input to which the video signal is applied as an input video signal and a signal output from which an output video signal is provided, said brightness controlling means being operable by a control signal for controlling the brightness of the video signal so that respective portions of said output video signal corresponding to portions of the input video signal at said peak dark level and at said peak bright level are provided substantially at said peak dark and bright levels while the average picture level of said output video signal is provided at a predetermined optimum level;

average picture level detecting means for detecting the average brightness level of at least one of said input and output video signals and providing said control signal in response to the detected average brightness level; and

a variable gamma correction circuit included in said brightness controlling means and having an input-output characteristic such that for the input video signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, said video signal is provided at a level proportional to a value X^{γ}; and the value of γ is automatically determined in response to the control signal from said average picture level detecting means.

2. A control circuit according to claim **1**; wherein said average picture level detecting means is connected to receive said input video signal in advance of said brightness controlling means to provide said control signal as a function of the average brightness level of said input video signal.

3. A control circuit according to claim **1**; wherein said average picture level detecting means is connected to receive said output video signal from said brightness controlling means to provide said control signal as a function of the average brightness level of said output video signal.

4. A correction circuit according to claim **1**; wherein said variable gamma correction circuit includes means for selecting the value of γ to be a number whose magnitude is less than unity when said average brightness level is detected to be less than said predetermined optimum level, to be unity when said average picture level is detected to be substantially at said predetermined optimum level, and to be a number greater than unity when said average brightness level is detected to be greater than said predetermined optimum level.

5. A control circuit according to claim **4**; wherein the value of γ is selected to be $\frac{1}{2}$ and 2, respectively when said average brightness level is detected to be less than and greater than said predetermined optimum level.

6. A control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level and a peak bright level about an average brightness level comprising:

brightness controlling means having a signal input to which the video signal is applied as an input video signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, and a signal output from which an output video signal is provided, said brightness controlling means being operable by a control signal for controlling the brightness of the video signal so that respective portions of said output video signal corresponding to portions of the input video signal at said peak dark level and at said peak bright level are provided substantially at said peak dark and bright levels while the average picture level of said output video signal is provided at a predetermined optimum level; said brightness controlling means including first correction circuit means having an input-output characteristic such that a first corrected video signal is provided at a level proportional to $\sqrt{X}$, second correction circuit means having an input-output characteristic such that a second corrected video signal is provided at a level proportional to X^2 and summing circuit means for combining said first and second corrected video signals in relative amounts depending upon said control signal so that the combined first and second corrected video signals are provided as said output video signal; and

average picture level detecting means for detecting the average brightness level of said input video signal and providing said control signal in response to the detected average brightness level.

7. A control circuit according to claim **6**; wherein said first correction circuit means includes a constant current source, an input transistor having an input electrode coupled to receive said input video signal and an output electrode coupled to said constant current source, an auxiliary transistor having a control electrode coupled with the output electrode of the input transistor and current carrying electrodes respectively coupled to the control electrode of the input transistor and to a reference point; and an output transistor having a control electrode coupled to the control electrode of said input transistor and an output electrode providing said first corrected video signal.

8. A control circuit according to claim 7; wherein said first correction circuit means further includes a diode coupled in advance of the control electrode of said input transistor; and wherein said second correction circuit means includes a constant current source, an input transistor having a control electrode coupled to receive said input video signal and an output electrode, a diode having one electrode coupled to the output electrode of the input transistor and another electrode coupled to said constant current source, and an output transistor having a control electrode coupled to said other electrode of said diode and an output electrode providing said second corrected video signal.

9. A control circuit according to claim 6; wherein said summing circuit means includes a load impedance; a voltage source; a first transistor having a control electrode coupled to receive said control signal, one current-carrying electrode coupled to said voltage source, and another current-carrying electrode coupled to receive said first corrected video signal; a second transistor having a control electrode, an input electrode coupled to said another current-carrying electrode of said first transistor, and an output electrode coupled to said load impedance; a third transistor having a control electrode, one current-carrying electrode coupled to said voltage source and another current-carrying electrode coupled to receive said second corrected video signal; means biasing the control electrodes of said second and third transistors to a predetermined level; a fourth transistor having a control electrode coupled to receive said control signal, an input electrode coupled to said other current carrying electrode of said third transistor, and an output electrode coupled to said load impedance; and output means coupled to said output impedance to provide said output video signal.

10. A control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level and a peak bright level about an average brightness level comprising:

brightness controlling means having a signal input to which the video signal is applied as an input video signal and a signal output from which an output video signal is provided, said brightness controlling means being operable by a control signal for controlling the brightness of the video signal so that respective portions of said output video signal corresponding to portions of the input video signal at said peak dark level and at said peak bright level are provided substantially at said peak dark and bright levels while the average picture level of said output video signal is provided at a predetermined optimum level; said brightness controlling means including correction circuit means having an input terminal to which said input video signal is applied and an output terminal at which a corrected video signal is obtained, the latter being substantially proportional to the square of the input video signal, polarity inverter means coupled to the output terminal of the correction circuit means for providing an inverted version of said corrected video signal, summing circuit means for combining said corrected video signal and the inverted version thereof in relative amounts depending upon said control signal to provide a resultant video signal and adder means for combining the input video signal with said resultant video signal to produce said output video signal; and

average picture level detecting means for detecting the average brightness level of said input video signal and providing said control signal in response to the detected average brightness level.

11. A control circuit according to claim 10; further comprising peak automatic gain control circuit means for controlling the strength of the input video signal in response to at least one peak value of said output video signal.

12. A color television camera providing a composite color video signal comprising a plurality of pickup tubes each responsive to light of a respective primary color to produce a corresponding primary-color signal that fluctuates between a peak dark level and a peak bright level about an average brightness level; average picture level detecting means for detecting the average brightness level of the composite color video signal and providing a control signal in response to such detected average brightness level; a plurality of variable correction circuits each coupled to a respective pickup tube for processing a respective primary color signal, each such variable correction circuit being coupled to receive said control signal and having an input-output characteristic such that for the associated respective primary-color signal having a level proportional to a value X, where X is in range $0 \leqq X \leqq 1$, said variable correction circuit provides an output signal substantially proportional to a value X^{γ}, where the value γ is automatically determined in response to the control signal from the average picture level detecting means; and encoding means coupled to receive the output signals from said variable correction circuits for providing said composite color video signal as a brightness-corrected composite color video signal.

13. A color television camera according to claim 12; wherein said composite color video signal includes a luminance component; and said average picture level detecting means includes a matrix circuit having inputs coupled to said plurality of pickup tubes and an output providing said luminance component, and also includes average luminance level detecting means coupled to said matrix circuit and responsive to said luminance component for providing said control signal.

14. A control circuit for controlling the brightness of a video signal in a color television display apparatus having a color display tube providing a color video picture in response to a plurality of primary color signals, and in which a chrominance signal and a luminance signal that varies between a black level and a peak white level about an average brightness level are combined to form said plurality of primary color signals, comprising

average picture level detecting means coupled to receive the luminance signal for detecting the average brightness level of said luminance signal and providing a control signal in response to the detected average brightness level; and a plurality of variable correction circuits each operative upon a respective primary color signal and disposed in advance of said color display tube, each such variable correction circuit being coupled to receive said control signal and having an input-output characteristic such that for the associated respective primary-color signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, said variable correction circuit provides to the associated respective beam-generating device, an output signal that is substantially propor-

tional to a value X^{γ}, where the value of γ is automatically determined in response to said control signal.

15. A correction circuit for controlling the brightness of a composite color video signal having a luminance component that fluctuates between a black level and a peak white level about an average luminance level, a chrominance component, and a synchronizing pulse with a pedestal portion, comprising clamping means for establishing the black level of said video signal as a function of said pedestal portion; means for providing said synchronizing pulse to said clamping means; average picture level detecting means for providing a control signal in response to the average luminance level of said luminance component; and brightness controlling means coupled to receive said control signal and having a signal input to which at least said luminance and chrominance components are applied and a signal output from which an output composite video signal is obtained, for controlling the brightness of the composite video signal so that respective portions of said output composite video signal corresponding to portions of the luminance component at said black level and at said peak white level are provided substantially at said black and peak white levels, while said output composite video signal has an average picture level that is provided at a predetermined optimum level.

16. A correction circuit according to claim **15**; wherein said brightness controlling means has an input-output characteristic that varies as a function of said control signal between occurrences of said synchronizing pulse but has a constant input-output charcteristic during occurrence of said synchronizing pulse.

17. A correction circuit according to claim **16**; further comprising synch signal slicing means in advance of said average picture level detecting means for blocking said synchronizing pulse.

18. A correction circuit according to claim **15**; further comprising separating means in advance of said clamping means for passing thereto said composite color video signal without said synchronizing pulse, said means for providing said synchronizing pulse having an input coupled in advance of said separating means; and wherein said brightness controlling means includes means for controlling the brightness of the clamped luminance and chrominance components to provide a corrected signal and adder means for combining the corrected signal with the synchronizing pulse to produce said output composite video signal.

19. A color video display apparatus to which is applied a composite color video signal including a chrominance component and a luminance component that fluctuates between a black level and a peak white level

about an average brightness level comprising separating means for separating said luminance component and said chrominance component from said composite color video signal; average picture level detecting means having an input coupled to receive the separated luminance component for providing a control signal in response to the detected average brightness level; variable luminance component controlling circuit means having an input to receive the separated luminance component, a signal output from which a corrected luminance component is provided, and a control input to receive said control signal, for controlling the brightness of the separated luminance component so that respective portions of the corrected luminance component corresponding to portions of the separated luminance component at said black and peak white levels are provided substantially at said black and peak white levels, while the average brightness level of said corrected luminance component is provided substantially at a predetermined optimum level; variable chrominance component controlling circuit means having an input to receive the separated chrominance component, a signal output from which a corrected chrominance component is provided, and a control input to receive said control signal, for controlling the strength of the separated chrominance component, and having an input-output characteristic that varies as a function of said control signal; processing circuit means to which said corrected luminance and chrominance components are applied for producing a plurality color signals; and display means for producing a picture in response to said primary color signals.

20. A color video display apparatus according to claim **19**; further comprising minimum value detecting means for detecting the minimum among the levels of said plurality of primary color signals; peak detecting means for detecting the peak value of such detected minimum level and providing a gain control signal in response thereto; luminance gain control means interposed between said separating means and said variable luminance component controlling circuit means for controlling the strength of said separated luminance component in dependence on said gain control signal; and chrominance gain control means interposed between said separating means and said variable chrominance component controlling means for controlling the strength of said separated chrominance component in dependence on said gain control signal.

21. A color video display apparatus according to claim **20**; further comprising an automatic chroma control circuit interposed between said separating means and said chrominance gain control means.

* * * * *

EXHIBIT B

United States Patent [19]
Song et al.
[11] Patent Number: 4,829,381
[45] Date of Patent: May 9, 1989

[54] **SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION**

[75] Inventors: **Woo-Jin Song**, Waltham; **Donald S. Levinstone**, Lexington, both of Mass.

[73] Assignee: **Polaroid Corporation**, Cambridge, Mass.

[21] Appl. No.: **182,987**

[22] Filed: **Apr. 18, 1988**

[51] **Int. Cl.**[4] **H04N 5/235**; H04N 5/208
[52] **U.S. Cl.** **358/168**; 358/166; 358/32; 358/164
[58] **Field of Search** 358/166, 167, 36, 37, 358/168, 169, 32, 164

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Primary Examiner—James J. Groody
Assistant Examiner—E. Anne Faris
Attorney, Agent, or Firm—Edward S. Roman

[57] **ABSTRACT**

A system and method are provided for continuously enhancing electronic image data received in a continuous stream of electronic information signals wherein the electronic information signal corresponding to each pixel of the image recorded is selectively transformed as a function of the average value of electronic information signals for a select plurality of pixel values in the immediate area of the pixel value being transformed. The electronic information signal transformations are provided on a pixel-by-pixel basis to increase contrast in localized areas that may be either exceptionally light or dark as a result of varying scene lighting conditions.

13 Claims, 2 Drawing Sheets

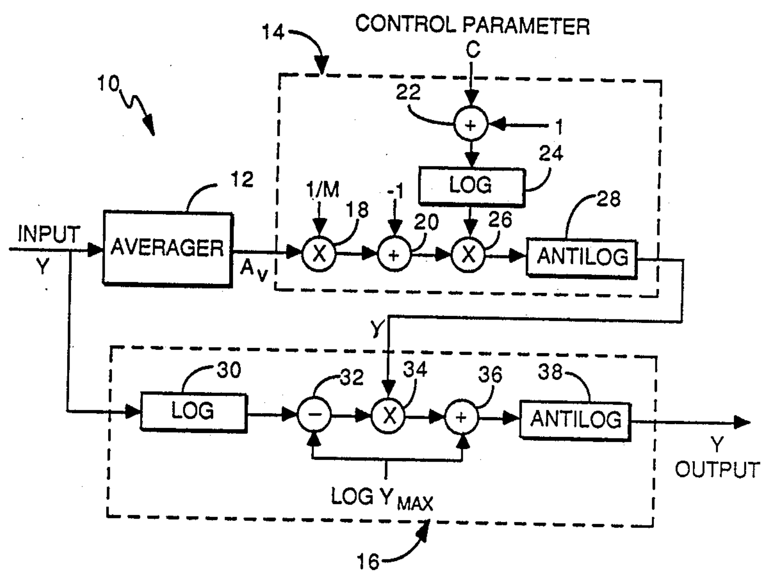


FIG 1

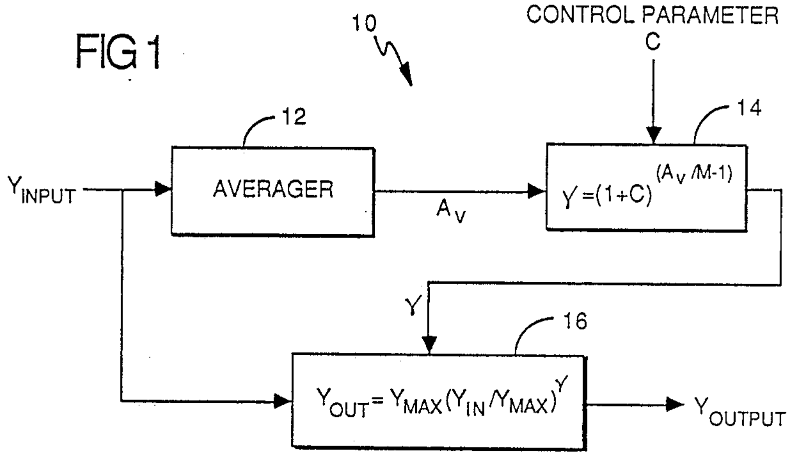
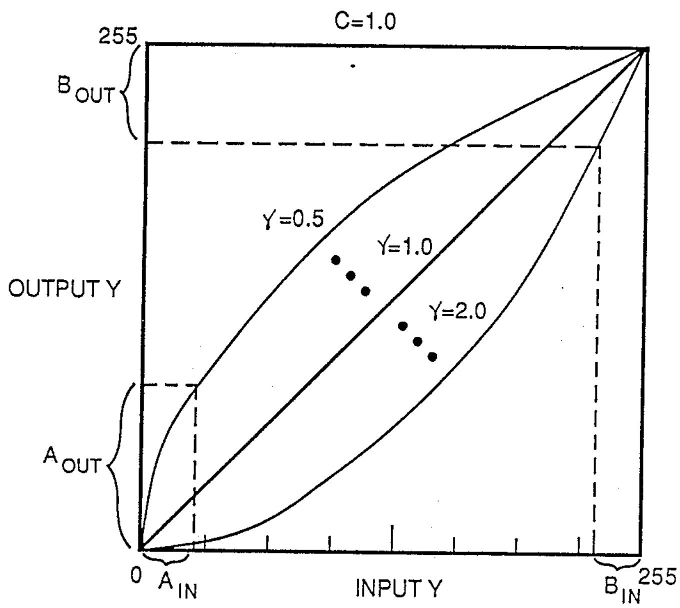
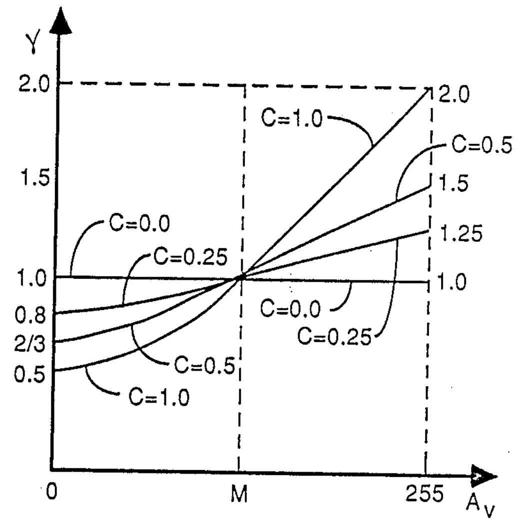

10
CONTROL PARAMETER
C
12
14
Y_{INPUT}
AVERAGER
A_V
$\gamma = (1+C)^{(A_V/M-1)}$
γ
16
$Y_{OUT} = Y_{MAX}(Y_{IN}/Y_{MAX})^{\gamma}$
Y_{OUTPUT}

FIG 2


C=1.0
255
B_{OUT}
γ=0.5
γ=1.0
γ=2.0
OUTPUT Y
A_{OUT}
0
A_{IN}
INPUT Y
B_{IN}
255


Y
2.0
1.5
1.0
0.8
2/3
0.5
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C=0.5
C=0.0
C=0.25
C=0.0
C=0.25
C=0.5
C=1.0
2.0
1.5
1.25
1.0
0
M
255
A_V

FIG 3

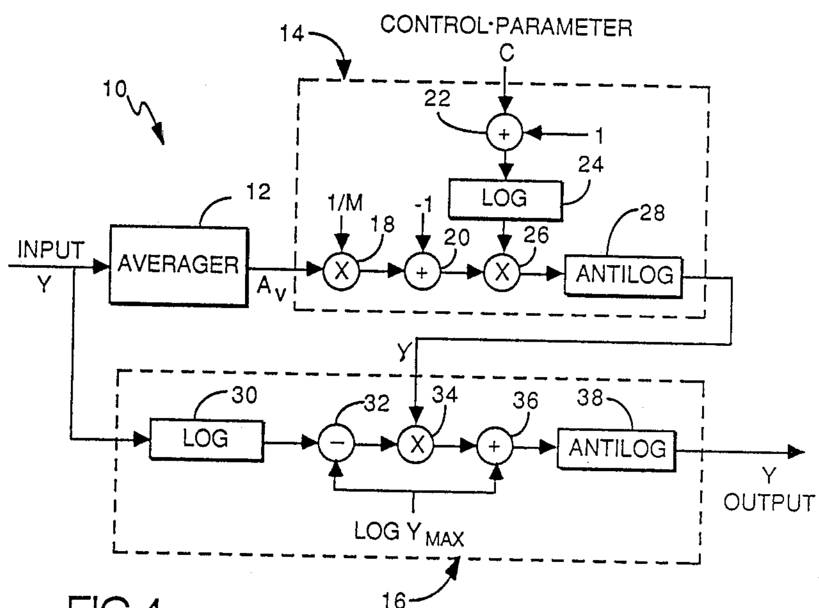
14
CONTROL·PARAMETER
C
10
22
+
1
24
LOG
12
1/M
-1
18
20
26
28
INPUT
Y
AVERAGER
A_V
X
+
X
ANTILOG
Y
30
32
34
36
38
LOG
−
X
+
ANTILOG
Y
OUTPUT
LOG Y_{MAX}
16

FIG 4

SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to a system and method for electronic image enhancement by dynamic pixel transformation and, more particularly, to a system and method for enhancing electronic image information by dynamically transforming electronic information signals on a pixel-to-pixel basis.

2. Description of the Prior Art

Electronic still image cameras are becoming well known in the art. Such cameras utilize photoresponsive arrays to sense scene light and convert the sensed scene light into electronic information signals. Electronic information signals are thereafter stored on a suitable media which may include magnetic, optical or solid state storage for subsequent retrieval and viewing. It may be desirable at some point to transform the stored image defining electronic information signals to a hard copy of the scene originally recorded. Photographic media have been suggested and used for such purposes. Difficulties arise, however, as a result of differences between the wide dynamic range of the scene originally sensed and recorded and the substantially smaller dynamic range to which a photographic print may be exposed. The wide dynamic range of luminance intensities within the scene originally recorded may thus be compressed or clipped to the substantially smaller dynamic range of the photographic print, losing detail within certain portions of the dynamic range that were otherwise visible in the original scene. Thus, it may be desirable to transform the original image defining electronic information signals in a nonlinear manner to selectively increase and/or decrease the contrast and brightness in certain portions of the scene such as those that might be brightly lit by sunlight or underlit as a result of shadows. However, no single transform function can be uniformly applied to all the image defining electronic information signals of the scene and achieve satisfying results because the lighting conditions vary across the scene.

Therefore, it is an object of this invention to provide a system and method of electronically enhancing images by dynamically increasing or decreasing contrast and brightness in selected portions of the scene that may be overlit or underlit.

It is a further object of this invention to provide a system and method of enhancing image defining electronic information signals in a dynamic manner on a pixel-by-pixel basis such that the value of each pixel is selectively transformed as a function of the average value of a plurality of pixels closely spaced about that pixel.

Other objects of the invention will be in part obvious and will in part appear hereinafter. The invention accordingly comprises a mechanism and system possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure.

SUMMARY OF THE INVENTION

A system is provided for enhancing electronic image data received in a continuous stream of electronic information signals wherein each signal corresponds to one of a plurality of succeeding pixels. The pixels collectively define the image to be recorded. Means are provided for averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each of the plurality of the pixels so averaged. Means operate to thereafter select one of the plurality of different transfer functions of electronic information signals for each of the succeeding pixels. Each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing that one pixel. The electronic information signal corresponding to each pixel is subsequently transformed by the transfer function selected for that pixel. The system responds to an average electronic information signal indicative of low scene light intensity levels by transforming electronic information signals to provide a higher contrast and/or brightness to those electronic information signals corresponding to pixels having the lowest scene light intensity levels. The system also responds to an average electronic information signal indicative of high scene light intensity levels by transforming electronic information signals to provide a higher contrast and/or lower brightness to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

DESCRIPTION OF THE DRAWINGS

The novel features that are considered characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with other objects and advantages thereof will be best understood from the following description of the illustrated embodiment when read in connection with the accompanying drawings wherein:

FIG. **1** is a block diagram showing the system for enhancing electronic image data in the manner of this invention;

FIG. **2** is a graphical representation showing the output electronic information signals versus the input electronic information signals;

FIG. **3** is a graphical representation showing the variation of gamma γ with different selected control parameters; and

FIG. **4** is a block diagram showing in substantially more detail a system for enhancing electronic image data of this invention in the manner of FIG. **1**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In electronic image processing it is desirable to adjust the image contrast automatically to produce more detail in both the bright and dark areas of a scene that is recorded. The image enhancing system and method of this invention operates to both lighten the dark regions of a scene and darken the light regions of a scene by enhancing contrast to improve the detail visibility that would otherwise be lost when the electronic image signals are converted to a hard copy reproduction. Toward that end, the system and method of this invention operates to continuously enhance electronic image data received in a continuous stream of electronic information signals, each signal of which corresponds to one of the plurality of succeeding pixels which collectively define the recorded image.

Referring now to FIG. 1, there is shown a block diagram for the system of this invention in which a continuous stream of electronic information signals each corresponding to one of a plurality of succeeding pixels from the recorded image are received at terminal Y_{input}. The electronic information signals input at terminal Y_{input} may be derived in a well-known manner by a two-dimensional photosensitive array or sensor (not shown) which may comprise a high resolution charge coupled device (CCD) or charge injection device (CID). The sensor receives image scene light in any well-known manner by way of an objective lens and shutter (also not shown). The image sensing array comprises a plurality of image sensing elements or pixels preferably arranged in a two-dimensional area array wherein each image sensing pixel converts the incident image defining scene light rays into a corresponding analog electronic information signal value. Preferably, the image sensing pixels are arranged in columns and rows as is well known in the art. As will be readily understood, image sensing arrays, particularly for sensing still images, preferably comprise a large number of image sensing elements or pixels in the order of 500,000 or greater.

The two-dimensional photosensitive arrays may also be overlayed with any one of a variety of different well-known filter patterns so that each pixel provides an electronic information signal value corresponding to a particular color. For instance, the columns of the two-dimensional photosensitive array may be overlayed with any one of a red, green or blue filter stripe arranged in a repeating fashion across the face thereof. The electronic information signal value for each pixel in this arrangement thus corresponds to a particular color.

The electronic information signal values retrieved from the photosensitive array in this manner are preferably converted to luminance (Y) and chrominance, e.g., (R-Y and B-Y) signal values. For the case where the two-dimensional photosensitive array is overlayed with red, green and blue filters, the luminance electronic information signals are preferably determined by the following relationship: $Y=0.30R+0.59G+0.11B$ as is well known in the television art. The analog luminance electronic information signal values for each pixel element of the photosensitive array for the example herein described are digitized to an 8-bit binary number so as to have a dynamic integer range of from 0 - 255 within which range are 256 intensity levels and a maximum luminance value of $Y_{MAX}=255$. The electronic image detection and processing herein described so far will be recognized as being conventional and well known in the art.

The image defining electronic information signals derived in the above-described manner and preferably comprising digitized luminance signals are thereafter subjected to a gain control function which may be automatic as is well known in the art before being directed to input terminal Y_{input} of the block diagram of FIG. 1. The image defining luminance electronic information signals are thereafter averaged for selected pluralities of pixels by an averager **12**. The averager **12** may comprise a low pass filter as is well known in the art which operates to provide an average value electronic information signal Av corresponding to the average luminance values for a selected window or plurality of pixels that continuously changes in correspondence with each succeeding pixel value to be enhanced. Alternatively, the averager may comprise a block average in which a selected group or block of pixel values is averaged to provide one average value electronic information signal Av in correspondence with each pixel value of that group to be enhanced. Succeeding groups of pixel values are thereafter averaged. In the preferred mode, the selected groups of pixels are preferably selected in two dimensions from the photosensitive array.

Both low pass filtering and block averaging require a buffer memory to hold the selected groupings of pixel values for averaging as is well known in the art. The low pass filter method results in a continuing change in the average value of the electronic information signal Av for each succeeding pixel thereby providing a more accurate determination of average values for selecting the appropriate transfer function in the manner of this invention to be described. However, as will be well understood, the low pass filtering technique requires a substantially increased computational capacity in comparison to block averaging; and, therefore, block averaging, although not as highly selective as low pass filtering, may be preferred in image enhancing applications where reduced computational capacity is desired. Low pass filtering and block averaging are both well-known techniques in the electronic arts and therefore need not be described in any further detail herein.

The average value for the image defining luminance electronic information signal (Av) is thereafter provided to a gamma determining circuit **14** which determines gamma as a function of the average value input thereto in accordance with the following relationship:

$$\gamma=(1+C)(Av/M-1)$$

In the above relationship M for this example is selected to be the center value of the dynamic range of the electronic information signals. As was previously stated, the electronic signal values for this example comprise 8-bit binary numbers having a dynamic range of 256. Thus, for this example, $M=128$. However, it will be readily understood that M may be selected to be any value within the dynamic range of the electronic information signals depending upon where the least image enhancement is desired. Thus, for the case where M is selected to be at the center of the dynamic range, image enhancement will have the greatest effect near the ends of the dynamic range and the least effect toward the center of the dynamic range. Selecting the value of M to be closer to the high end of the dynamic range will decrease the effective image enhancement provided at that end by the system and method of this invention.

C is a control parameter selected in the manner of this invention to vary the amount of image enhancement that may be provided by the system and method of this invention in a manner to be more fully described in the following discussion.

The value of gamma is thereafter directed to a transfer function imposing circuit **16** which operates to impose the following transfer function on the image defining luminance electronic information signals (Y) received at input terminal Y_{input} and corresponding to each one of the succeeding pixels which collectively define the recorded image.

$$Y_{out}=Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

Y_{MAX} equals the highest value of the dynamic range for the electronic information signals or 255 for the example herein described. Y_{out} equals the image defining

luminance electronic information signal transformed in the manner of this invention to provide an enhanced image. As is now readily apparent, it is selected for the image defining luminance electronic information signal for each pixel as a function of a local average of image defining luminance electronic information signals for a select group or plurality of pixels closely spaced about the pixel value being enhanced or transformed. Thus, gamma γ changes continuously in correspondence with the average values from the continuous stream of succeeding image defining luminance electronic information signals so that each image defining luminance electronic information signal is enhanced or transformed by a selected one of a plurality of different transfer functions.

Referring now to FIG. **2**, there is shown a graphical representation of the various transfer functions that are imposed by the transfer function circuit **16** as a function of the variation in gamma γ. For the example as shown in FIG. **2**, the control parameter C is selected to equal 1 and thus it can be seen that gamma γ has a variation of from 0.5 to 2. For instance, in the situation where the average value of the image defining luminance electronic signals is high and approaches the maximum value of the dynamic range which in this example equals 255 and is indicative of a portion of the image that is extremely bright, it can be seen that gamma γ equals $1+C$ or as in the case where $C=1$, gamma $\gamma=2$ as shown in the diagram of FIG. **2**. The slope of the transfer function as is readily apparent for the situation where gamma $\gamma=2$ becomes quite steep at the high end of the dynamic range (B_{in}, B_{out}) thereby providing a higher contrast to those image defining luminance electronic information signals corresponding to pixels having the highest scene light intensity levels. The slope of the transfer function for $\gamma=2$ decreases significantly at the low end of the dynamic range (A_{in}, A_{out}) thereby providing a lower contrast to those image defining luminance electronic information signals corresponding to pixels having the lowest scene light intensity levels. Since M is selected to be at the center of the dynamic range, it can be seen that the slope of the transfer function at the center of the dynamic range most closely approximates that of a straight line thereby providing the least effect on the output signal for pixels having intensity levels near the center of the dynamic range.

Conversely, in the situation where the average values of the image defining luminance electronic information signals are low approaching 0 indicative of localized areas of low scene light intensity levels, then gamma $\gamma=1$ divided by $1+C$ which equals 0.5 in the case where $C=1$. The transfer function imposed by the transfer function circuit **16** in the case where gamma γ equals 0.5 is shown graphically in FIG. **2** as comprising a substantially steep slope in the areas (A_{in}, A_{out}) where the image defining luminance electronic information signal values are low. Thus, the transfer function in this case where gamma γ equals 0.5 operates to transform the image defining luminance electronic information signals to provide a high contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels. The slope of the transfer function for $\gamma=0.5$ decreases significantly at the high end of the dynamic range (B_{in}, B_{out}) thereby providing a lower contrast to those image defining luminance electronic information signals corresponding to pixels having the highest scene light intensity levels. Again, since M is selected to be at the center of the dynamic range, it can be seen that the slope of the transfer function at the center of the dynamic range most closely approximates that of a straight line thereby providing the least effect on the output signal for pixels having intensity levels near the center of the dynamic range. It can be seen that the transfer function imposed by the transfer function circuit **16** can have any intermediate number of transfer functions shown between the extreme end transfer functions where gamma equals 0.5 or 2.0 and that all of the transfer functions are operative for the full extent of the input dynamic range so as not to clip the input signal values.

In the situation where the average value for the image defining luminance electronic information signal values corresponds to the intermediate value of the dynamic range, gamma $\gamma=1$ and the transfer function becomes a straight line to provide a one-to-one relationship between the input and output electronic information signals with no localized increase in contrast as provided by the other transfer functions where gamma γ is either greater or less than 1. Thus, in this manner in a situation where a scene may have localized dark or bright areas, there may be provided a localized increase in the contrast to those areas to make visible details that otherwise would be lost. The transfer functions vary in correspondence with the variation in the local average scene light intensity levels so as to apply the increased contrast selectively to those light or dark portions of the scene where details are otherwise obscured.

Referring now to FIG. **3**, there is shown a graphical representation of the variation in gamma γ as a function of the variation of the control parameter C. Thus, it can be seen that for a control parameter C value of 1 gamma γ varies from 0.5 to 2. If the control parameter C is selected to be 0, gamma γ remains constant at 1. Although for a typical imaging application which requires dynamic range compression, it may be satisfactory to select the control parameter C to equal 1 thereby achieving an extreme variation in gamma from 2 to 0.5, it may be desirable to increase the amount of localized contrast thereby selecting values of the control parameter C greater than 1.

Referring now to FIG. **4** where like numerals reference previously discussed components, there is shown a circuit diagram for implementing a transfer function as described in connection with FIG. **1**. The aforementioned transfer function may be converted to the following relationship by taking the logarithm on both sides of the aforementioned equation.

$$\log Y_{out}=\log Y_{MAX}+\gamma(\log Y_{in}-\log Y_{MAX})$$

Similarly, the relationship for determining gamma can also be rewritten as follows:

$$\log \gamma=(Av/M-1)[\log(1+C)]$$

These relationships can be implemented as shown by the circuit of FIG. **4**. The average value of the image defining luminance electronic information signal is first directed to a multiplier circuit **18** where the signal is multiplied by 1/M where M equals one-half the dynamic range of the electronic information signals as previously discussed. The output from the multiplier circuit **18**, in turn, is directed to a combining circuit **20** which operates to add a negative 1 to the output from the multiplier circuit **18**. The control parameter C is directed to a combiner circuit **22** which operates to add

a positive 1 thereto. The output from the combiner circuit 22, in turn, is directed to a log circuit 24 which provides the logarithmic value for the C+1 input thereto. The output from the logarithmic circuit 24, in turn, is multiplied by the output from the combining circuit 20 by a multiplier circuit 26. The output from the multiplier circuit 26, in turn, is directed to an antilogarithmic determining circuit 28 which operates utilizing a lookup table to provide the antilogarithm creating the value of gamma γ.

The image defining luminance electronic information signal for each pixel, in turn, is directed to a logarithm determining circuit 30 in the transfer function circuit 16. The output from the logarithm determining circuit 30, in turn, is directed to a combiner circuit 32 which operates to subtract therefrom the logarithm for the maximum dynamic range of the electronic information signals. The output from the combiner 32, in turn, is multiplied by multiplier circuit 34 by the value of gamma γ received from the antilogarithm determining circuit 28. The output from the multiplier 34, in turn, is directed to a combiner circuit 36 for addition to the logarithm of the maximum dynamic range of the electronic information signals. The output from the combiner circuit 36, in turn, is directed to an antilogarithm determining circuit 38 to provide the transformed image defining luminance electronic information signals Y_{out} as shown. Thus, in this manner, gamma γ is determined continuously in accordance with the relationship as shown by the block diagram of FIG. 1 in a simple and convenient manner utilizing multiplication circuits, combining circuits, logarithm determining circuits, and antilogarithm determining circuits as shown in FIG. 4. In like manner, the transfer function continuously varied in accordance with the selection of gamma may also be imposed continuously in a simple and convenient manner by circuitry comprising a logarithm determining circuit, combining circuits, multiplication circuit, and an antilogarithm determining circuit. Thus, in this manner localized dynamic contrast enhancement can be provided as a function of dynamic gamma transformation on a pixel-by-pixel basis.

Thus, the system and method of this invention provides for enhancing electronic image data in a manner involving a relatively small number of computations that can be easily calculated in a continuous manner. All of the transfer functions that can be invoked are of a continuous nature without any sharp discontinuities that could otherwise result in undesirable artifacts appearing in the final image. In addition, as previously mentioned, none of the transfer functions operate to clip any portion of the incoming electronic information signal, thus resulting in the entire dynamic range of the incoming signal being transformed.

Other embodiments of the invention including additions, subtractions, deletions and other modifications of the preferred disclosed embodiments of the invention will be obvious to those skilled in the art and are within the scope of the following claims.

What is claimed is:

1. A system for continuously enhancing electronic image data received in a continuous stream of electronic information signals, each signal having a value within a determinate dynamic range of values and corresponding to one of a plurality of succeeding pixels which collectively define an image, said system comprising:

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged; and

means for selecting one of a plurality of different transfer functions for the electronic information signal for each of the succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel and for subsequently transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel wherein said selecting and transforming means further operates to select said transfer function as a function of the ratio of the value of the average electronic information signal to the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

2. The system of claim 1 wherein said selecting and transforming means is responsive to an average electronic information signal indicative of low scene light intensity levels for transforming the electronic information signals to provide a higher contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels and is further responsive to an average electronic information signal indicative of high scene light intensity levels for transforming the electronic information signals to provide a higher contrast to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

3. The system of claim 2 wherein said selecting and transforming means further operates to select said transfer function as a function of a determined constant whose value corresponds to the amount of contrast provided in those areas of higher contrast provided by said select transfer function.

4. The system of claim 3 wherein said selecting and transforming means further operates to determine the select transfer function as a function of the determination of gamma (γ), said selecting and transforming means including means for determining gamma (γ) in accordance with the relationship

$$\gamma=(1+C)(Av/M-1)$$

where C equals said determined constant, Av equals the average electronic information signal value and M equals a select proportionate value of the dynamic range of the electronic information signals.

5. The system of claim 4 wherein said transforming means transforms the electronic information signal of each pixel in accordance with the relationship

$$Y_{out}=Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

where Y_{in} equals the value of the electronic information signal of the pixel to be enhanced, Y_{out} equals the enhanced value of the input electronic information signal and Y_{MAX} equals the highest value of the dynamic range for the electronic information signals.

6. A system for enhancing electronic image data received in a continuous stream of electronic information signals each signal having a value within a determinate dynamic range of values and corresponding to one of a

plurality of succeeding pixels which collectively define an image, said system comprising:

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged;

means for dividing each of the average electronic information signals corresponding to each pixel by a value M corresponding to a select proportionate value of the dynamic range of said electronic information signals;

first means for subtracting 1 from each of the electronic information signals output by said dividing means;

first means for adding a select control parameter and 1;

first means for determining the logarithm of the output from said first adding means;

first means for multiplying the output from said first logarithm determining means by the output from said first subtracting means;

first means for determining the antilogarithm of the output from said first multiplying means;

second means for determining the logarithm for each of the continuous streams of electronic information signals;

second means for subtracting the logarithm for a value corresponding to the maximum value of the electronic information signals from the output of said second logarithm determining means;

second means for multiplying the output of said first antilogarithm determining means by the output from said second subtracting means;

second means for adding the logarithm of the value corresponding to the maximum value of the electronic information signals to the output from said second multiplying means; and

second means for determining the antilogarithm of the output from said second adding means to provide an enhanced output signal value.

7. A method for continuously enhancing electronic image data received in a continuous stream of electronic information signals each signal having a value within a determinate dynamic range of values and corresponding to one of a plurality of succeeding pixels which collectively define an image, said method comprising the steps of:

averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels;

selecting one of a plurality of different transfer functions for the electronic information signal for each of the plurality of succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel; and

transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel wherein said transfer function is selected further as a function of the ratio of the value of the average electronic information signal to a select proportionate value of the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

8. The method claim 7 wherein the transfer function is selected: in response to an average electronic information signal indicative of low scene light intensity levels to provide a higher contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels and in response to an average electronic information signal indicative of high scene light intensity levels to provide a higher contrast to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

9. The method of claim 8 wherein said transfer function is selected further as a function of a determined constant wherein increasing the value of said constant operates to increase the contrast in those areas of higher contrast provided by said select transfer function.

10. The method of claim 9 wherein said transfer function is selected as a function of the determination of gamma (γ) and gamma (γ) is determined for each pixel in accordance with the relationship

$$\gamma=(1+C)(Av/M-1)$$

where C equals said determined constant, Av equals the average electronic information signal value and M equals said value for one-half the dynamic range of the electronic information signals.

11. The method of claim 10 wherein said select transfer function for the electronic information signal of each pixel comprises the relationship

$$Y_{out}=Y_{MAX}(Y_{in}/Y_{MAX})\gamma$$

where Y_{in} equals the value of the electronic information signal of the pixel to be enhanced, Y_{out} equals the enhanced value of the input electronic information signal and Y_{MAX} equals the highest value of the dynamic range for the electronic information signals.

12. A method for enhancing electronic image data received in a continuous stream of electronic information signals each signal corresponding to one of a plurality of succeeding pixels which collectively define an image, said method comprising the steps of:

averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels;

dividing each of the average electronic information signals corresponding to each pixel by a value M corresponding to a select proportionate value of the dynamic range of said electronic information signals;

subtracting 1 from each of the electronic information signals previously divided by the value M to provide a first intermediate signal value;

selecting a control parameter C as a function of the amount of image enhancement to be applied;

adding 1 to the control parameter C;

determining the logarithm of the control parameter C plus 1;

multiplying the logarithm of the control parameter C plus 1 by said first intermediate signal value to provide a second intermediate signal value;

determining the antilogarithm of the second intermediate signal value;

determining the logarithm for each of the continuous streams of electronic information signals;

subtracting from the previously determined logarithm for each of the continuous streams of electronic information signals the logarithm for a value corresponding to the maximum value of the electronic information signals to provide a third intermediate signal value;

multiplying the antilogarithm of the second intermediate signal value by the third intermediate signal value to provide a fourth intermediate signal value;

adding the logarithm of the value corresponding to the maximum value of the electronic information signals to the fourth intermediate signal value to provide a fifth intermediate signal value; and

determining the antilogarithm of the fifth intermediate signal value to provide an enhanced output signal value.

13. The method of claim **12** wherein said image enhancement operates to increase image contrast locally in areas of pixels having low contrast and said control parameter C is determined as a function of the amount of local contrast variation to be provided.

* * * * *

EXHIBIT C

REDACTED
IN ITS ENTIRETY